Solar Photospheric, Chromospheric and Coronal Observations Relevant for Space Weather Forecasting

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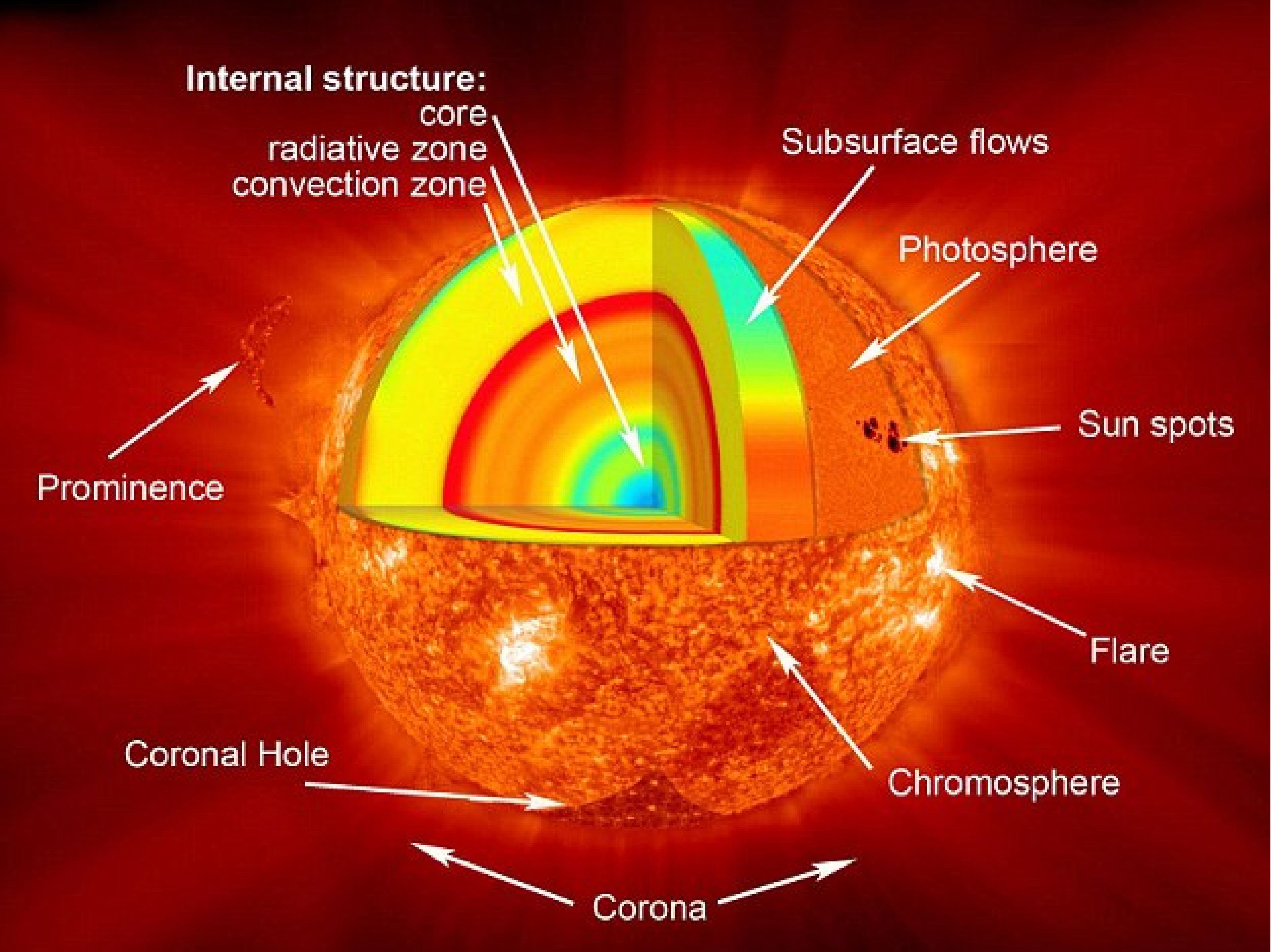
NASA/GSFC and CUA

SW-REDI 2018


Internal structure:
core
radiative zone
convection zone
Subsurface flows
Photosphere
Sun spots
Prominence
Flare
Coronal Hole
Chromosphere
Corona

Large-scale structures in the solar atmosphere

Solar large-scale structures relevant for Space Weather forecasting:

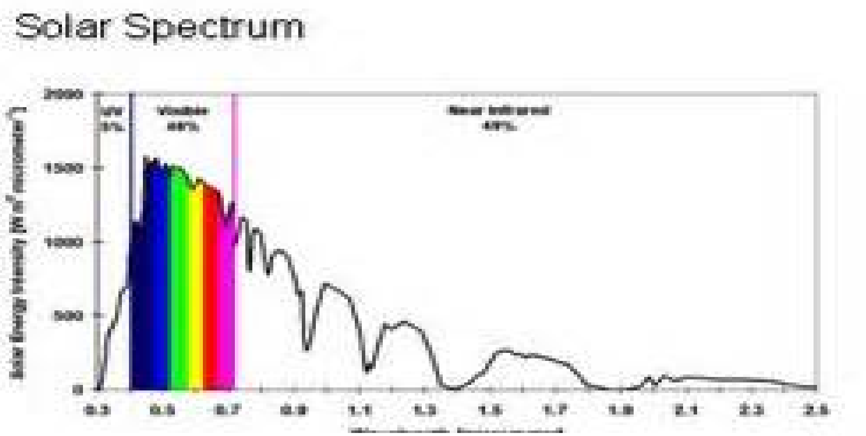
- Active regions
- Filaments/prominences
- Coronal holes
  (see talk by Michael Kirk, 'Coronal Holes and SWx')

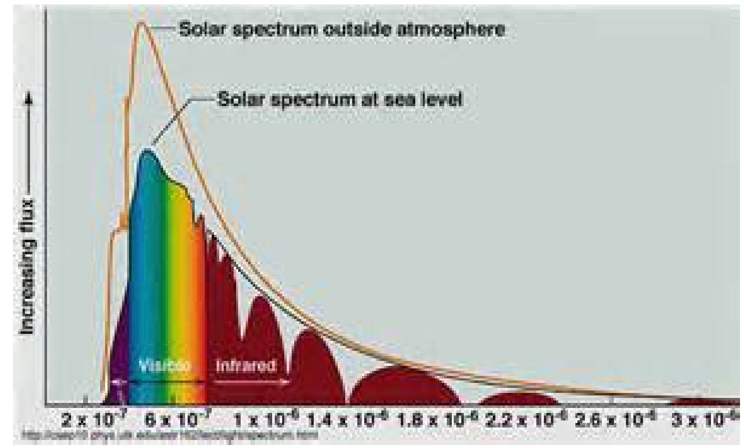
Large-scale structures in the solar atmosphere

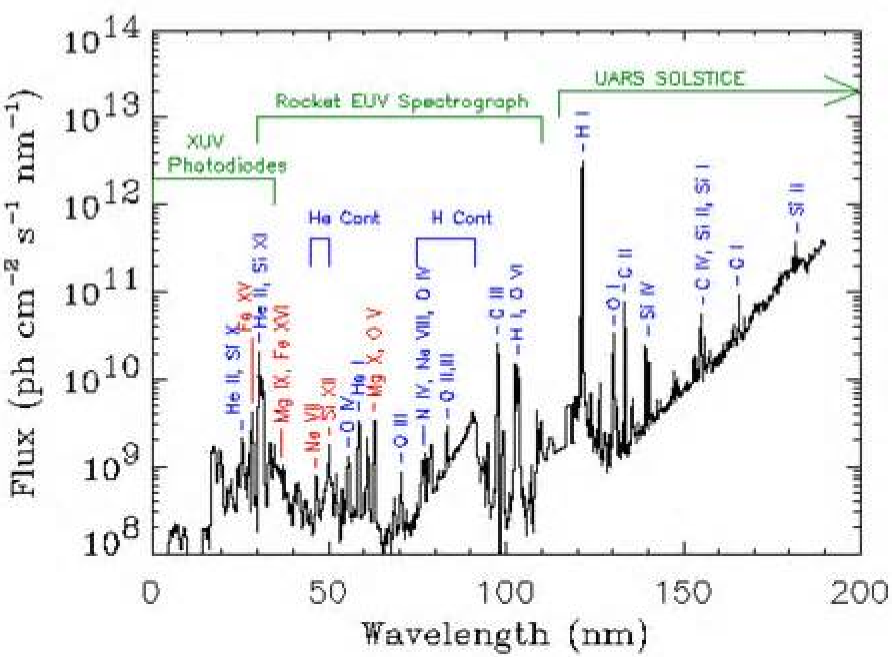
two kinds of measurement to collect information about the Sun:

Remote Sensing and In-situ Measurement

Key for remote sensing of the sun (and stars): Solar Spectrum







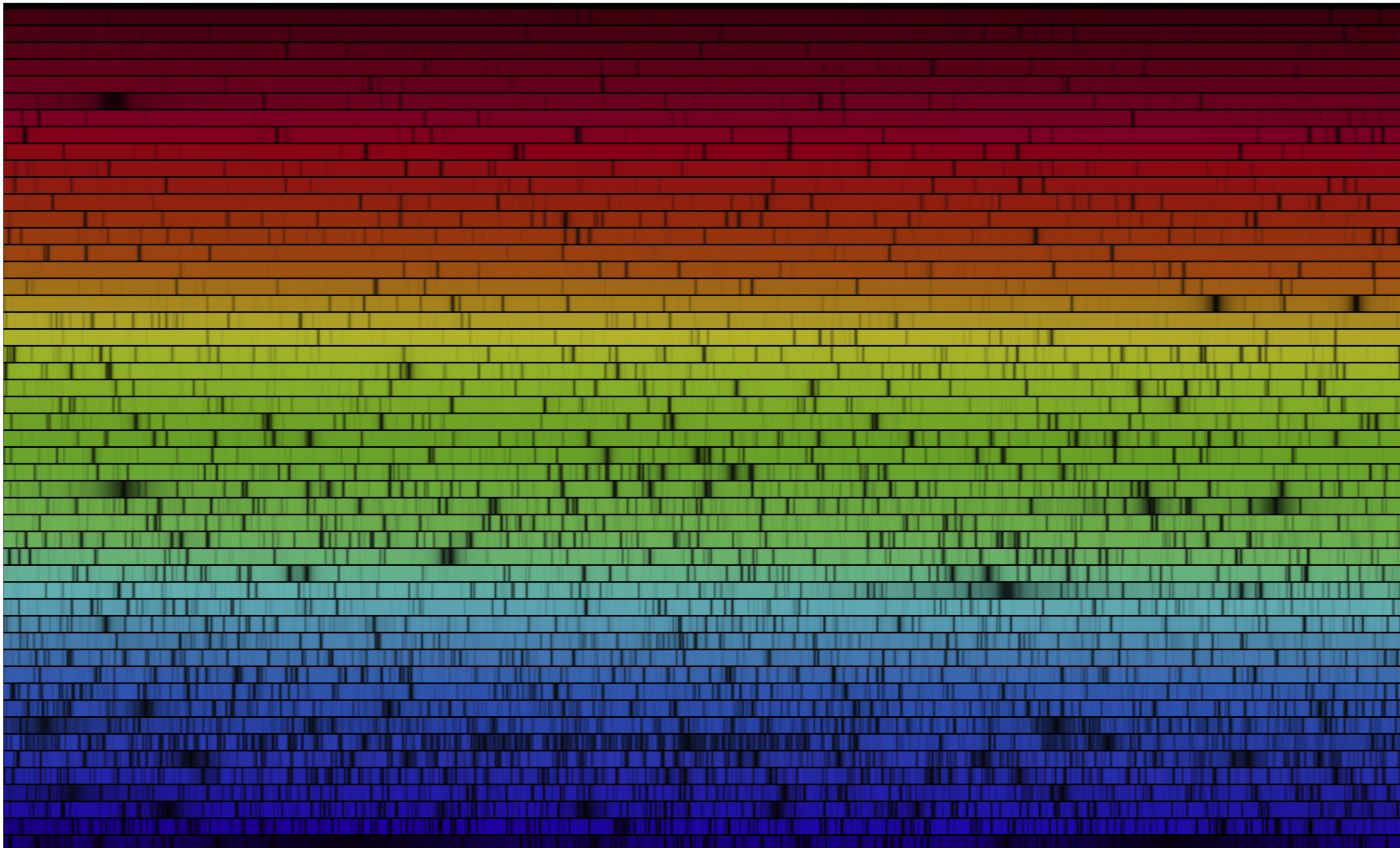
complete solar spectrum

and

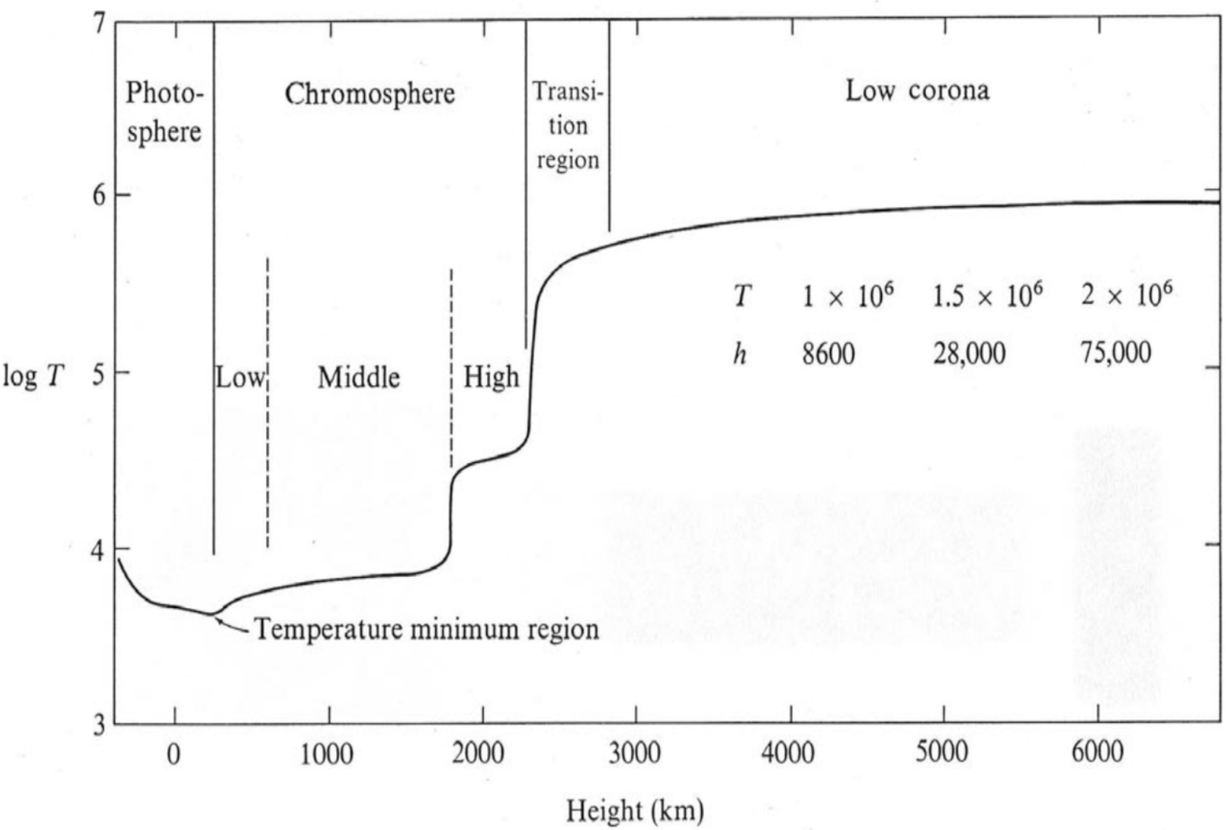
EUV part of solar spectrum

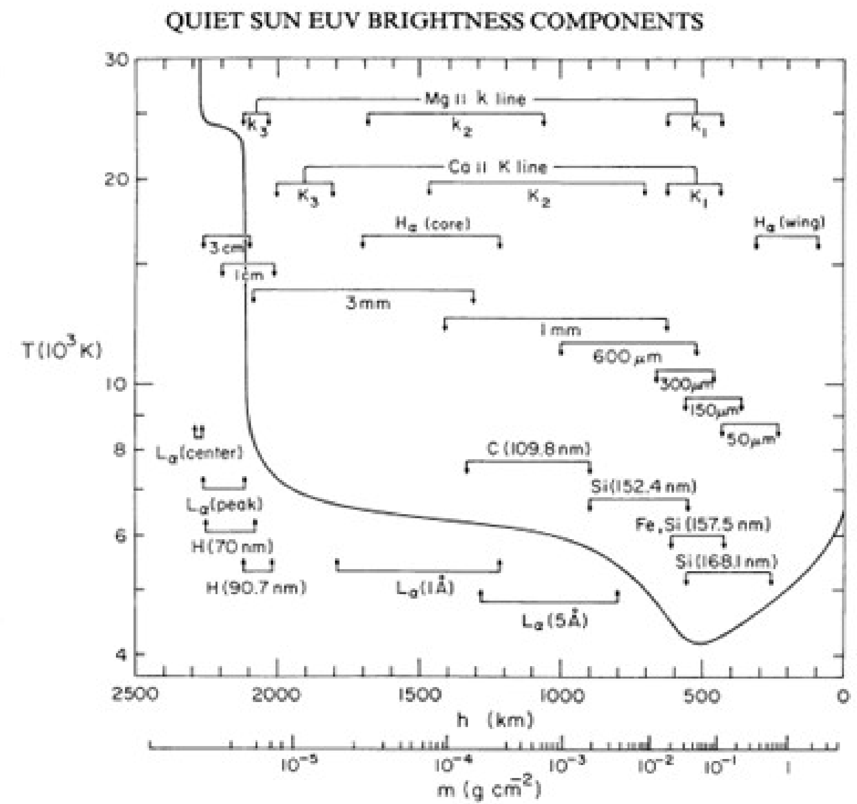
Key for remote sensing of the sun (and stars): Solar Spectrum

True-Color Irradiance Spectrum 392 to 692 nm from Kitt Peak Residual Irradiance Atlas (Kurucz 2005)



Average temperature profile of the solar atmosphere

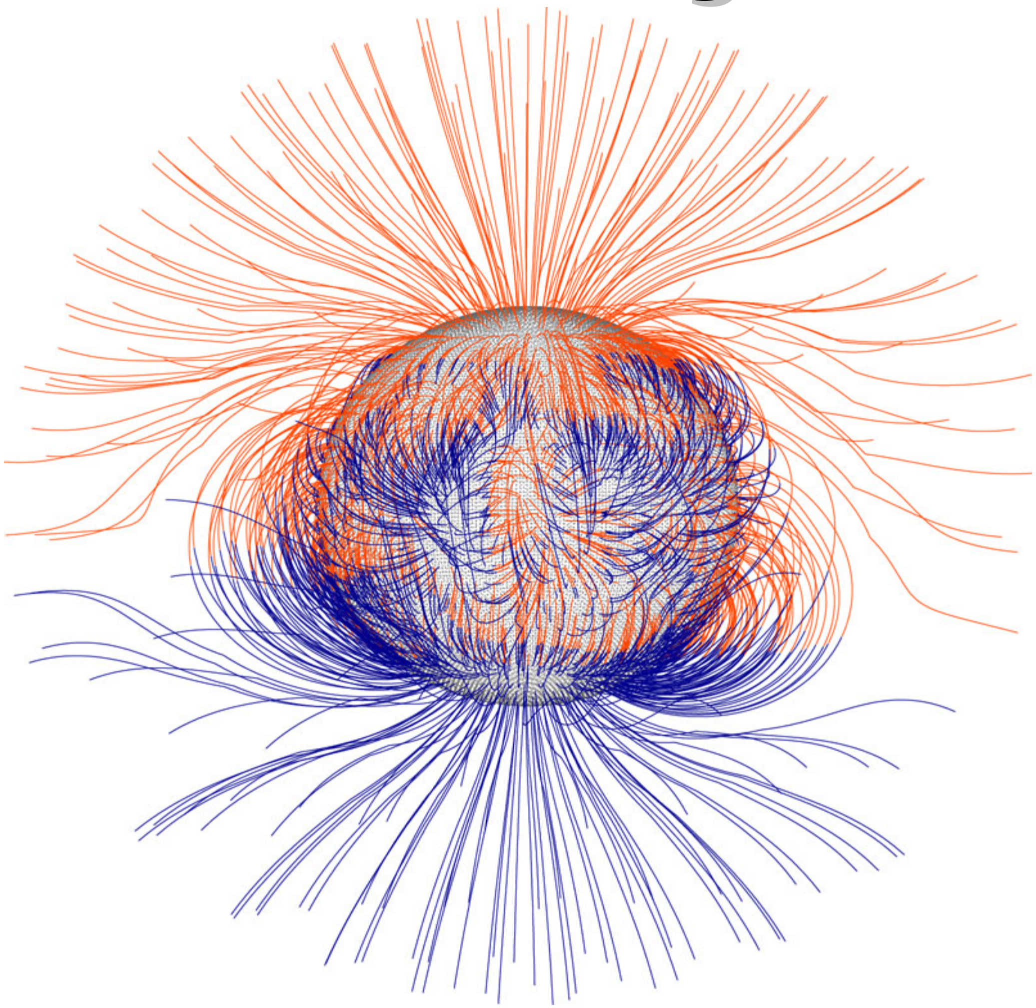


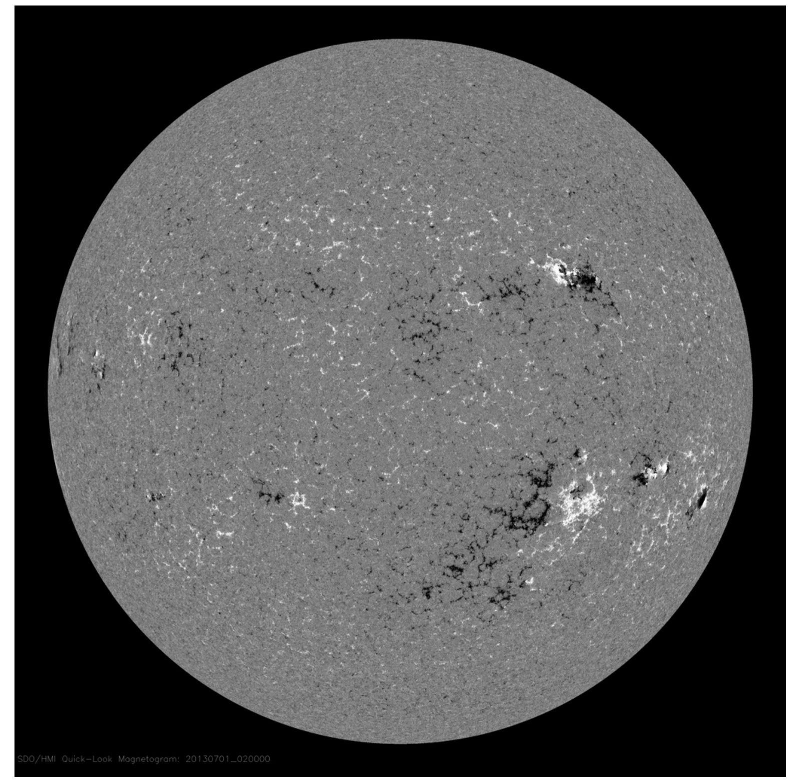


erage quiet-Sun temperature distribution derived from the EUV continuum, the Lα line, and other approximate depths where the various continua and lines originate are indicated.

Plasma temperature is roughly related to height/atmospheric layer and related to spectral line

Key for understanding solar activity: the solar magnetic field

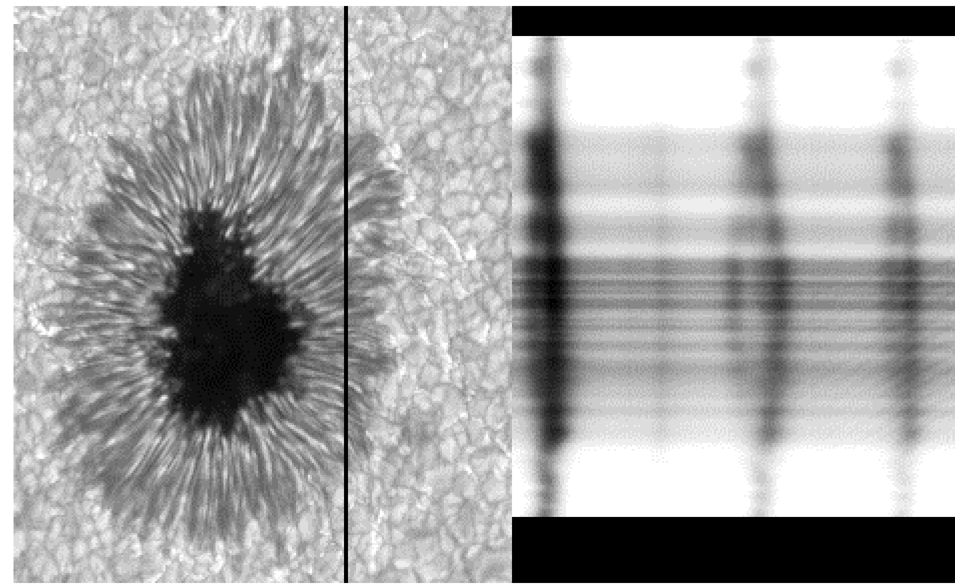




Global magnetic field (extrapolation): 3d structure

Line-of-sight full disk magnetogram: 2d cut at photosphere

Key for understanding solar activity: the solar magnetic field



How to measure the solar magnetic field?

- In-situ: magnetometer
- Remote: magnetographs

Method: Zeeman Effect:

a magnetic field in a plasma produces:

- splitting of certain spectral lines (mostly photospheric and chromospheric)
- polarisation of light

Key for understanding solar activity: the solar magnetic field

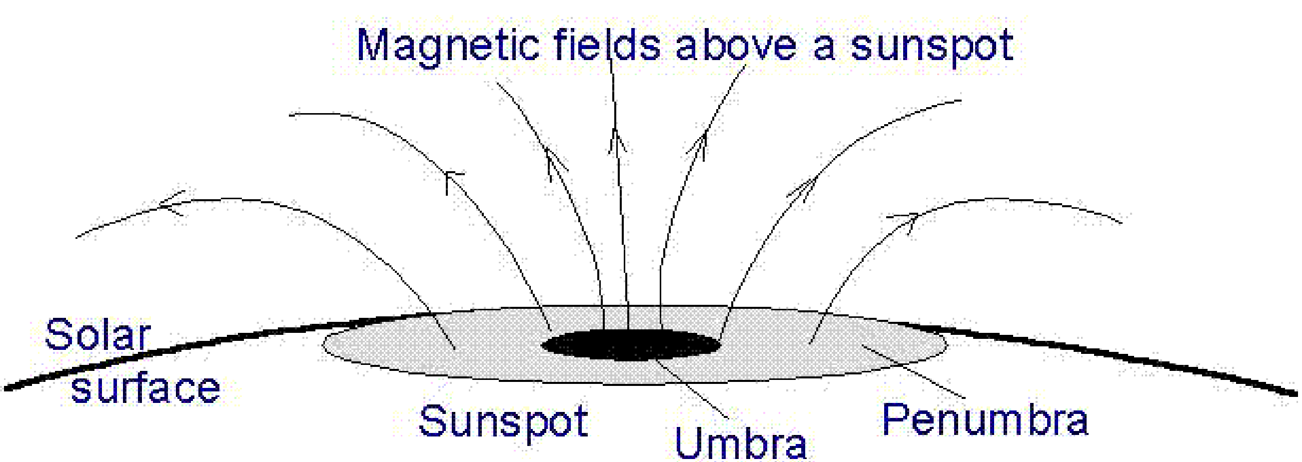
Zeeman Effect:

Longitudinal Zeeman Effect:

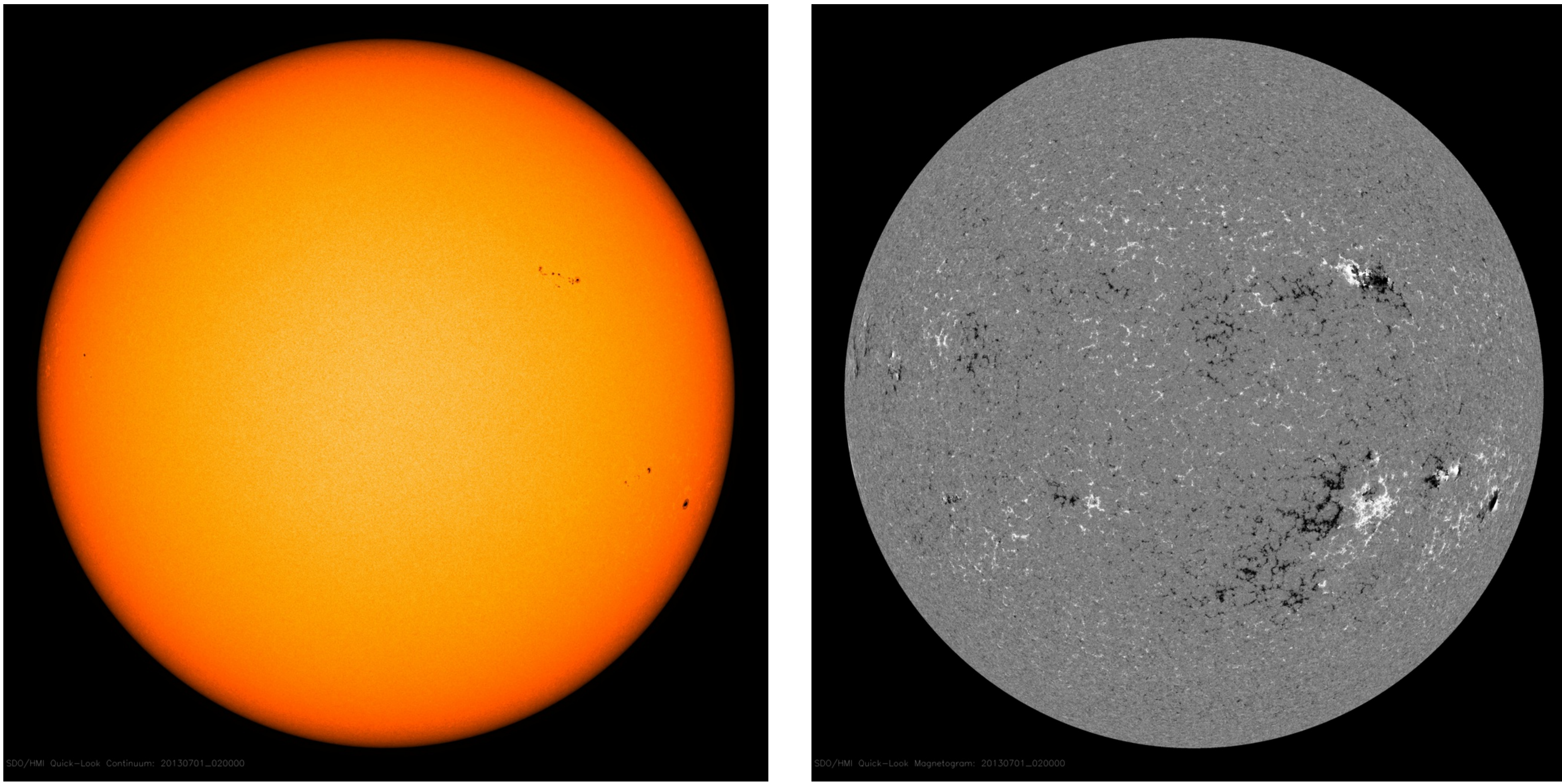
the component of the magnetic field vector parallel to the line of sight produces circular polarization

Transverse Zeeman Effect:

the component perpendicular to the line of sight produces linear polarization of light



Key for understanding solar activity: the solar magnetic field



Full disk white light image (SDO), full disk line-of-sight magnetogram (SDO)

Key for understanding solar activity: the solar magnetic field

If we just have white light images and magnetograms:

Q: How are the polarities connected?

Key for understanding solar activity: the solar magnetic field

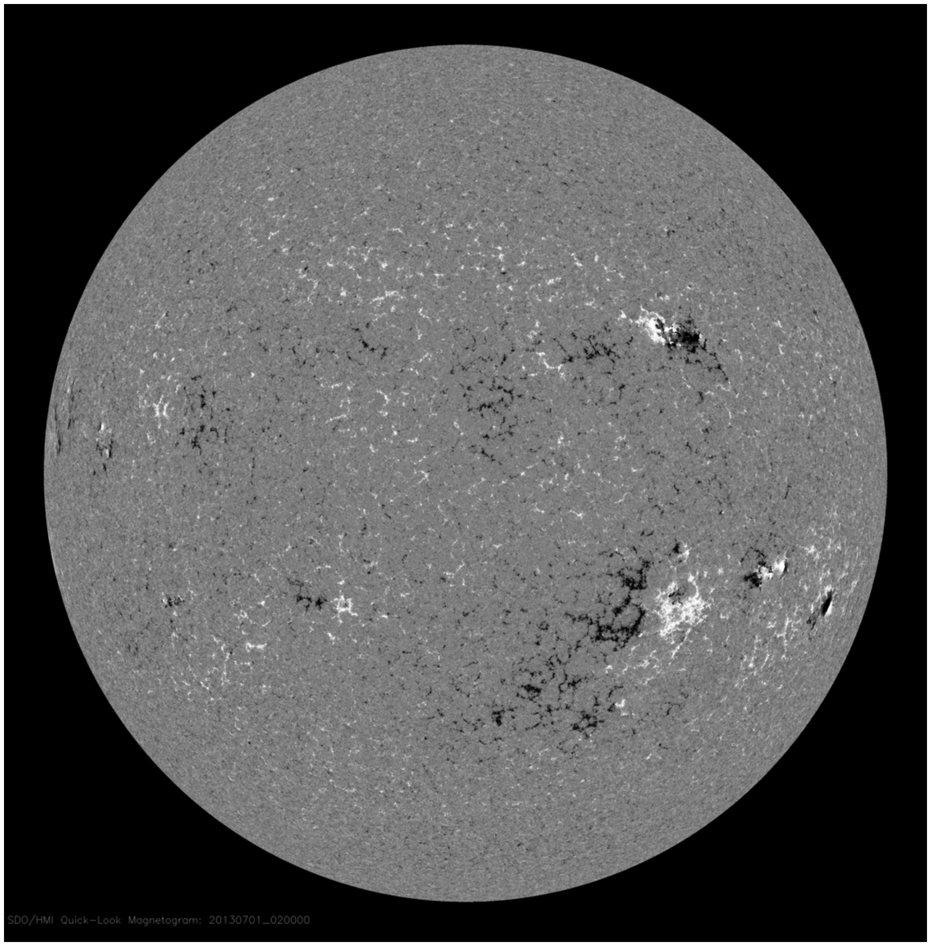
If we just have white light images and magnetograms:

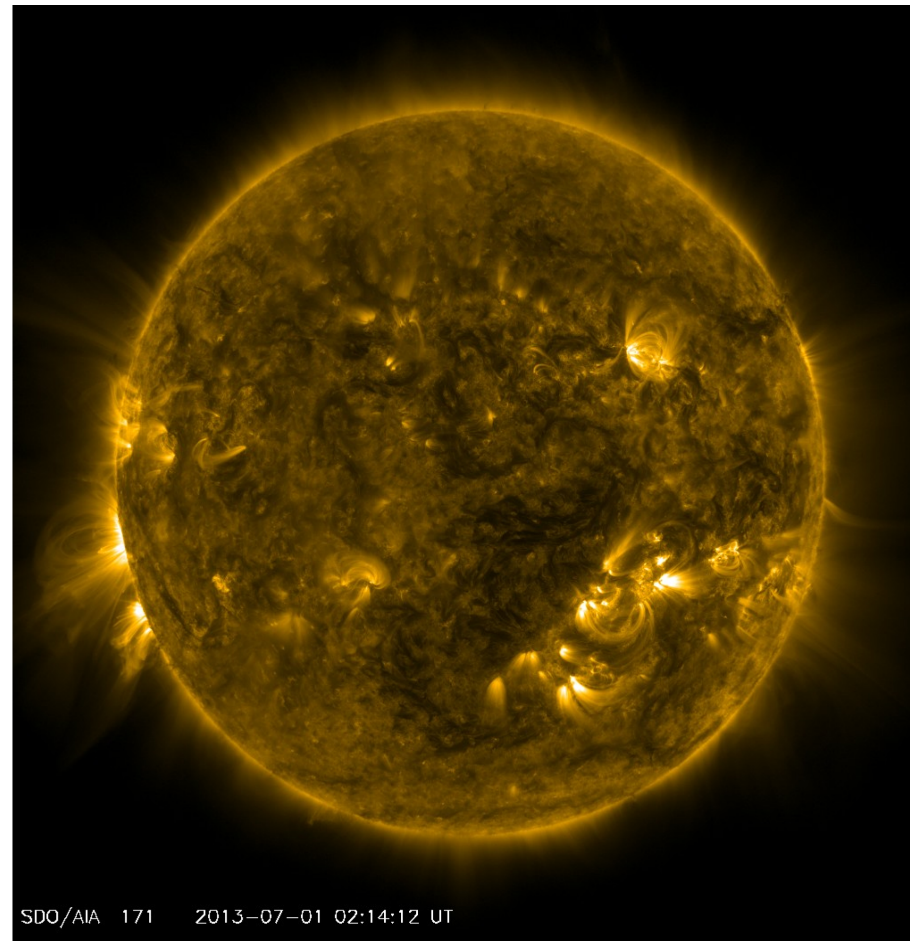
Q: How are the polarities connected?

A1: extrapolation

A2: images of the corona: outline (some, not all) of the magnetic field connectivity!

Key for understanding solar activity: the solar magnetic field

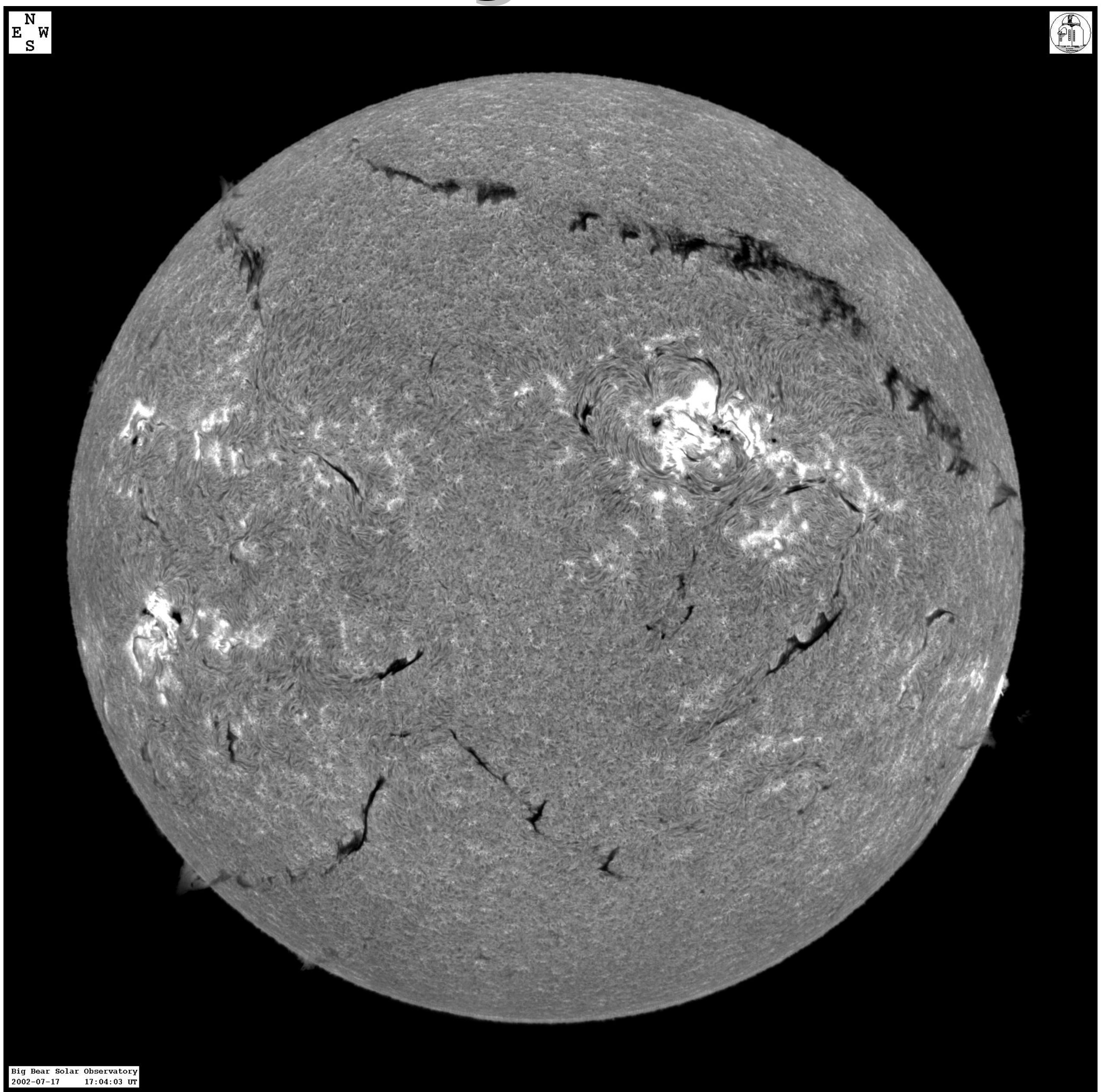




SDO full disk magnetogram and coronal 171 A image:

bright regions in corona are active regions (have stronger magnetic field than surrounding atmosphere)

Key for understanding solar activity: the solar magnetic field

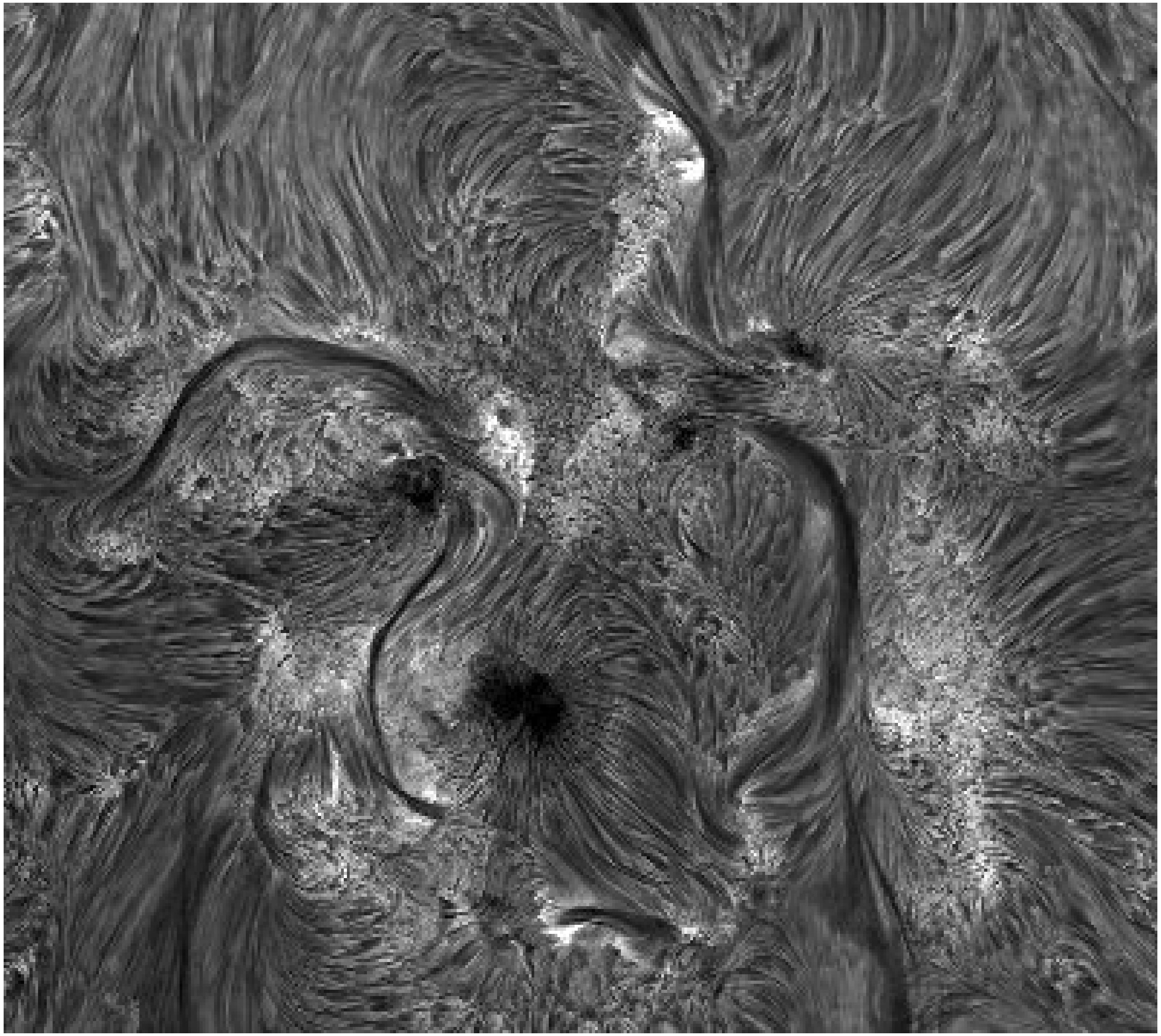


Full disk image in H alpha

(from BBSO):

filaments seen as dark absorption structures

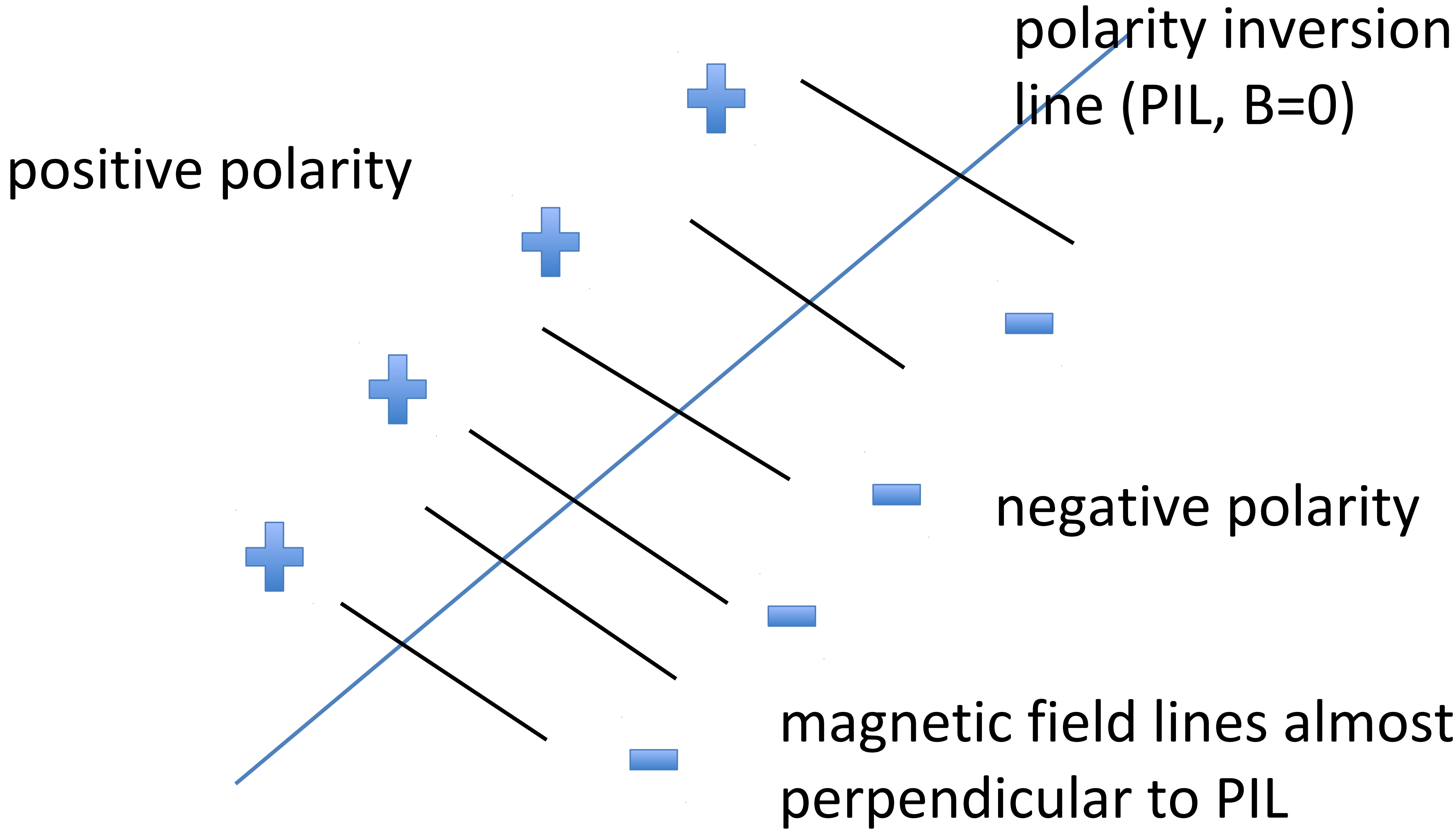
Key for understanding solar activity: the solar magnetic field



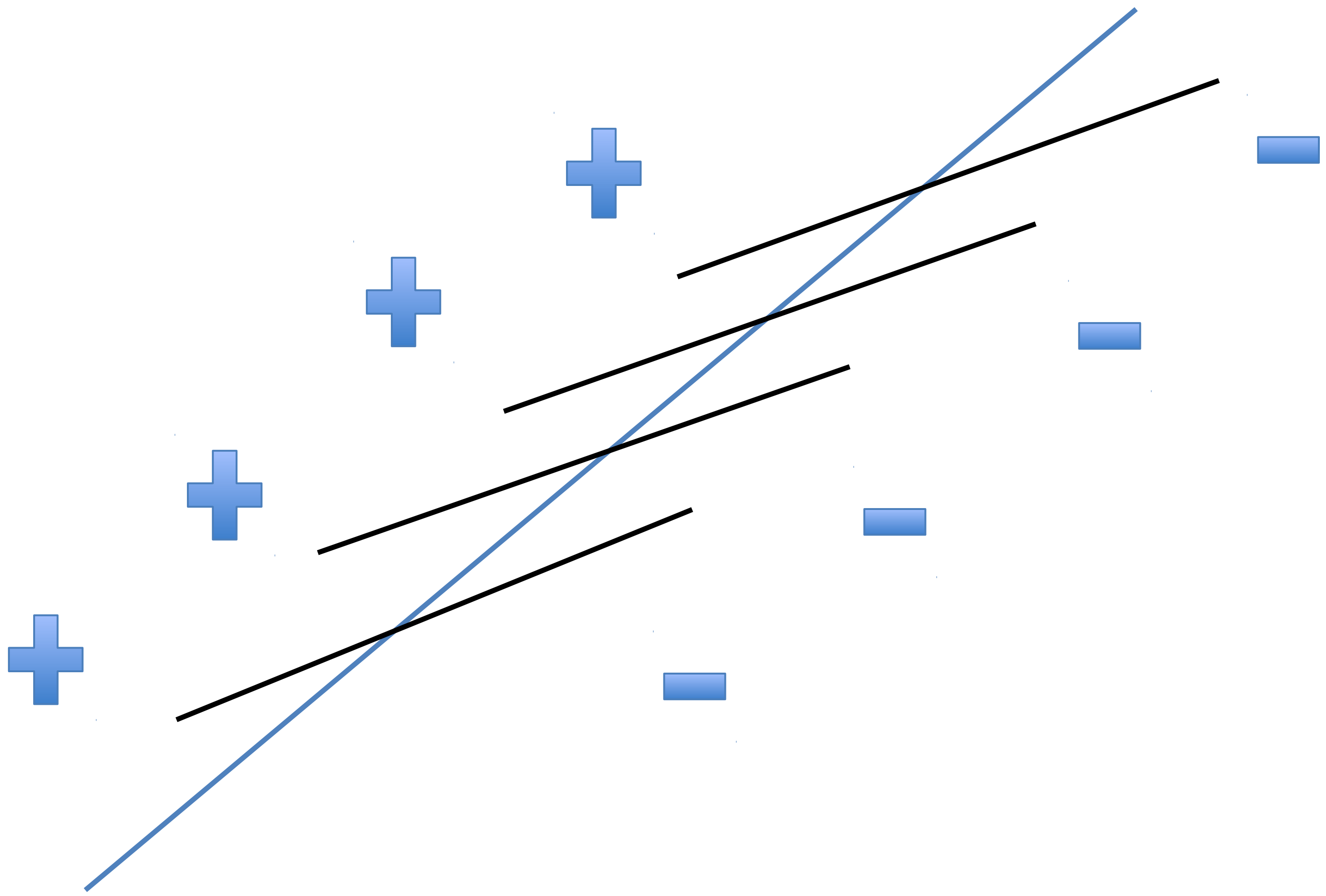
High resolution image in H alpha (Dutch Open Telescope)

filaments seen as dark absorption structures

SIMPLE (!!) cartoon of active region magnetic field



SIMPLE (!!) cartoon of filament magnetic field



magnetic field lines almost parallel to PIL

Key for understanding solar activity: the solar magnetic field

Notes on filaments:

Filament: on-disk magnetic structure (seen in absorption)

Prominence: same structure off limb (seen in emission)

Best wavelengths: H alpha, He II 304, Fe XII 195 A (AIA, STEREO)

All filaments have a PIL (polarity inversion line)

But not all PILs are filaments!

Caution: full disk magnetograms give only the line-of-sight magnetic field – projection effects near the solar limb! (see ISWA layout of active region near the limb and near disk center, link on agenda web-page.)

Key for understanding solar activity: the solar magnetic field

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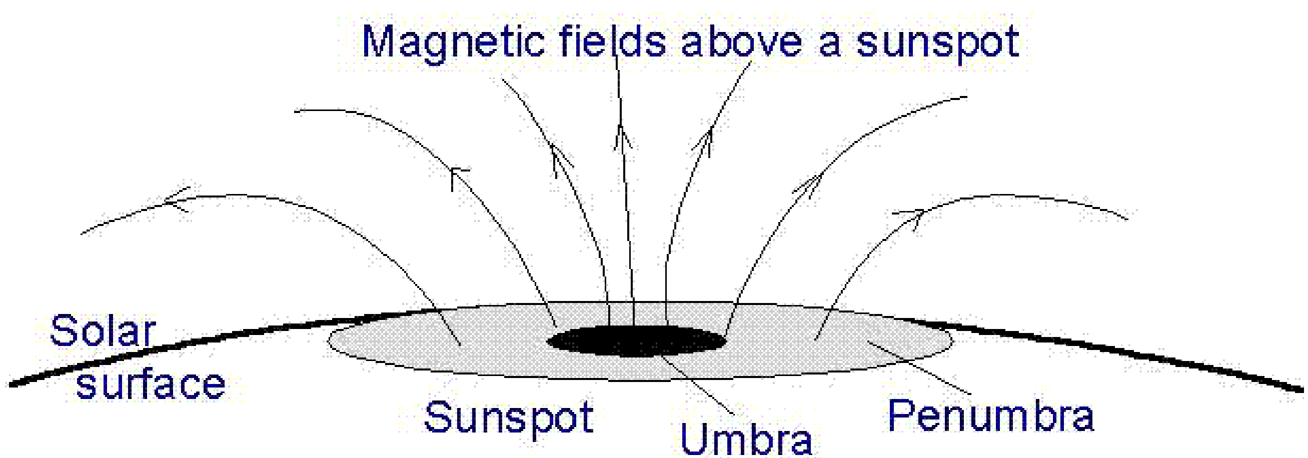


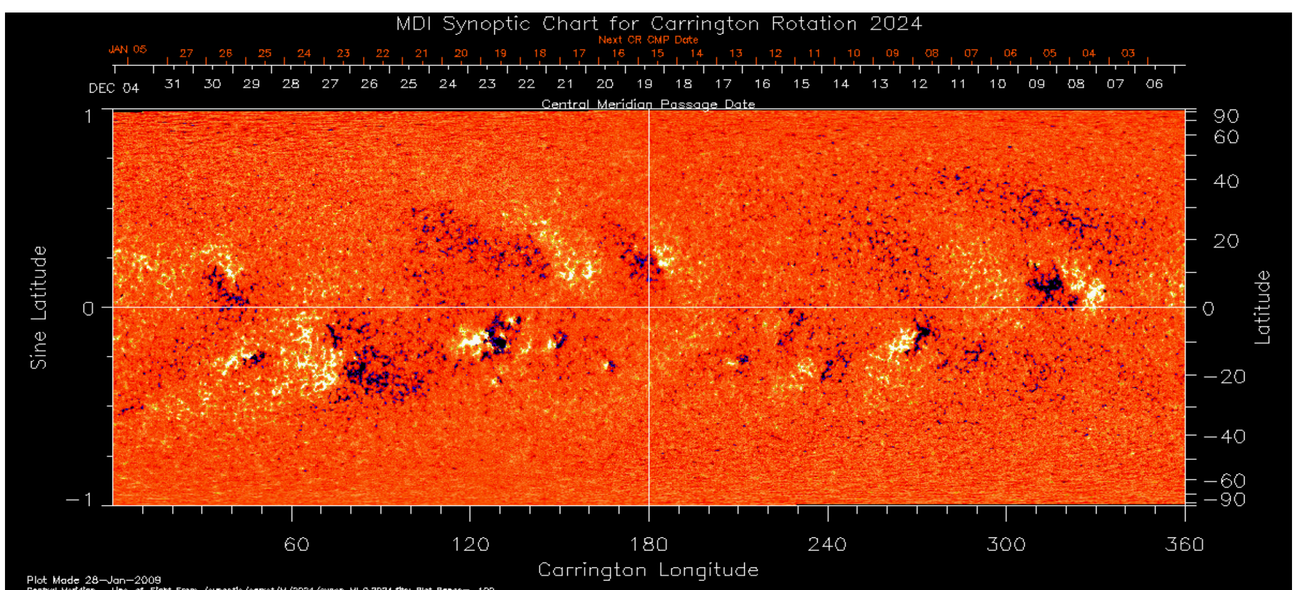
Key for understanding solar activity: the solar magnetic field

Solar magnetograms: Problems:

Most full-disk magnetographs measure circular polarization only! (MDI, HMI 45s, ground-based magnetograms like GONG), not very reliable beyond 60 deg from disk center!

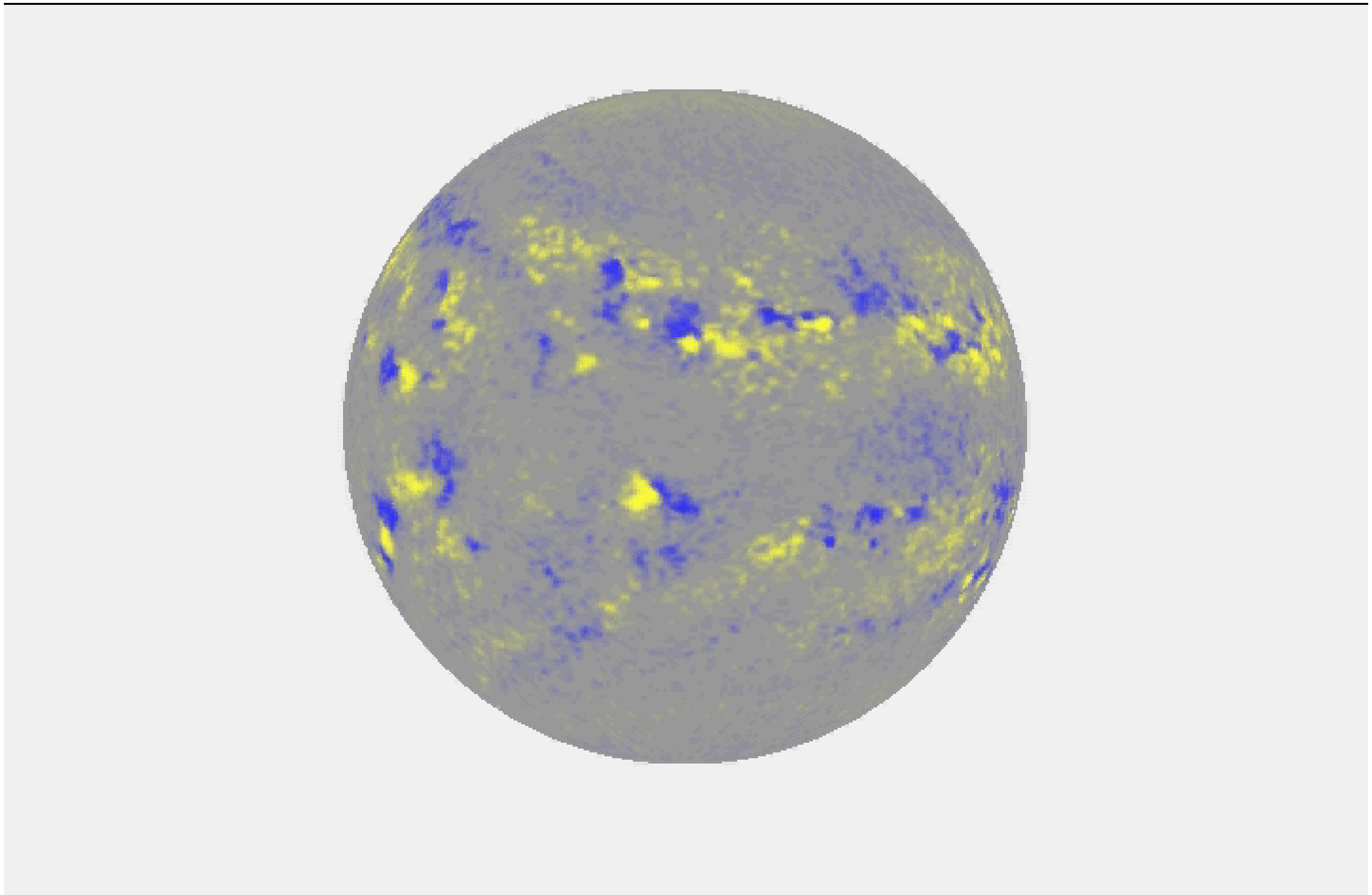
No magnetograph data on the far side of the sun!

To produce global magnetograms use solar rotation (27.27 d rotation rate) to get synoptic maps of the photospheric magnetic field. Due to tilt angle of solar rotation axis, poles of the sun are also not well observed!



Key for understanding solar activity: the solar magnetic field

Synoptic magnetograms over 30 years
(find more information on
https://solarscience.msfc.nasa.gov/dynamo.shtml)



More on the use of these magnetic field maps in the talk by Nick Arge ('Coronal Modeling with WSA and ADAPT')

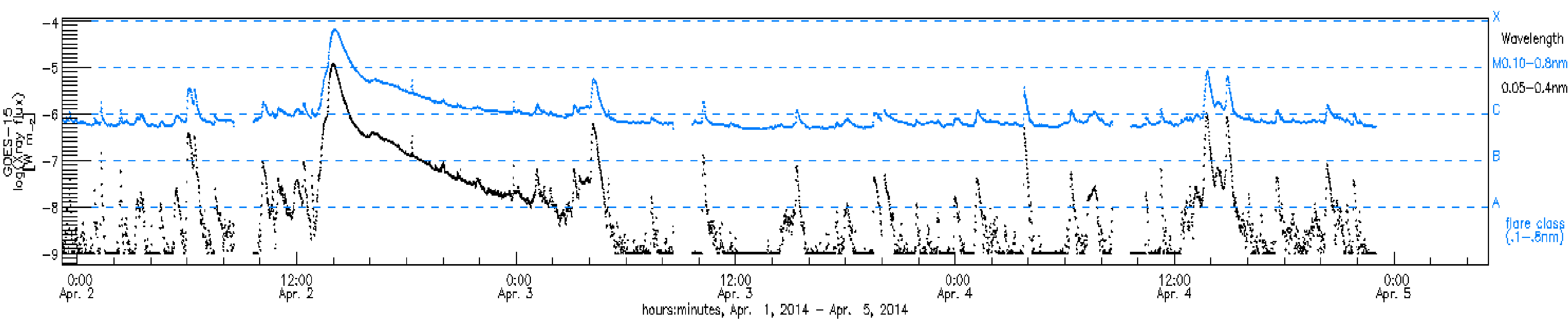
Solar eruptive events: flares and CMEs

- Energy is stored in the solar magnetic field (active regions and filaments): accumulated over a long period of time – days, weeks, months
- Energy is released in eruptive events (flares, CMEs): in a short time scale (minutes, hours)

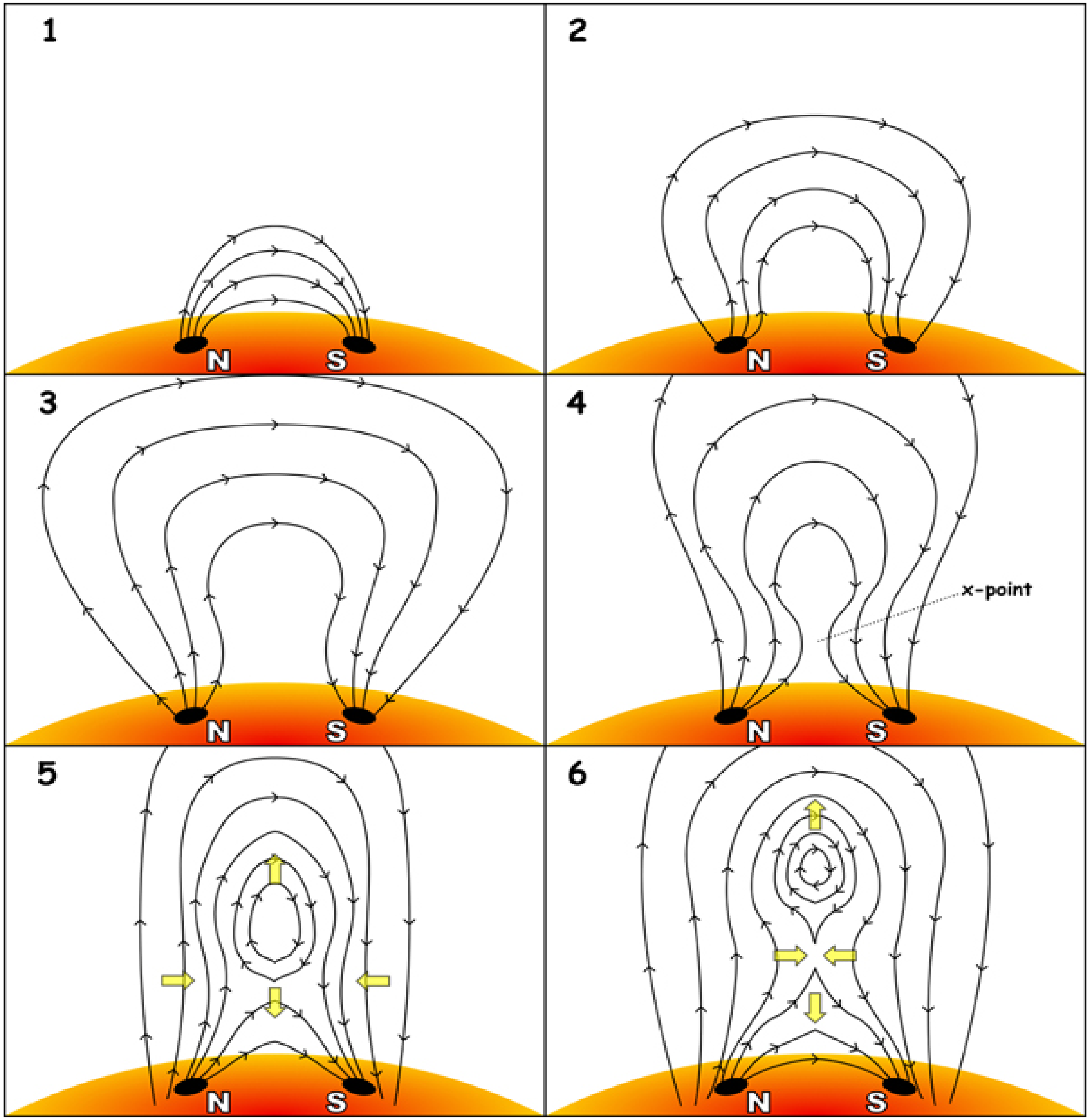
Magnetic energy is converted to thermal energy (and radiative energy) and kinetic energy (e.g. mass motion in CMEs and SEPs)

Solar eruptive events: flares and CMEs

- Solar Flares: Event that releases X-rays
- X-ray monitor on-board GOES spacecraft (in Earth orbit), full disk monitor (no spatial information of location of flare on the sun)
- larger events radiate also in other wavelengths especially in UV, EUV (and radio) → use SDO/AIA images to determine location!



Solar eruptive events: flares and CMEs



one possible scenario for an eruption:

- Reconnection at the x-point (energy release)
- CME escapes upward, field-lines open up
- Post-eruptive loops appear below x-point (additional heating)

Solar eruptive events: flares and CMEs

Caution: the real sun is more complicated compared to the cartoon – e.g. magnetic field is a

3d structure

- some eruptions show no/very little X-ray signature (particularly filament eruptions)
- some flares have no CMEs

Large scale structures in the corona

- Images: SDO AIA 193 A, STEREO EUVI 195 A

  (filter contains Fe XII 195 A line, T~1.5 MK)
- Line-of-sight magnetograms: polarity inversion line (PIL)

- Active Regions: bi-polar, bright (emission), closed magnetic field (field lines perpendicular to PIL)
- Filaments: bi-polar, dark (absorption), closed magnetic field (field lines parallel to PIL)
- Coronal hole: uni-polar, dark (less dense), open magnetic field

Coronal signatures of CMEs

- Data to use: SDO AIA, STEREO EUVI (A & B)

- Brightenings: flares, post-eruptive arcade (193 A), arcade footpoints (304 A, 193 A)
- Darkenings: dimmings (transient coronal holes), dark/absorbing/cool material rising (filament eruption)
- Off-limb: opening of closed coronal field lines, AIA 304 A emission structure
- Not a signature of eruption: active region loop brightenings, (small) flares

Coronal signatures of CMEs

Good period to study: 2014-02-18 - 2014-02-21
(use SDO AIA 211, 193, 304)

Data Sources

SDO: Solar Dynamics Observatory

(https://sdo.gsfc.nasa.gov)

SDO AIA: Atmosheric Imaging Assembly

full disk coronal images (wavebands 171A, 193A, 304A, 211A,131A,...)

SDO HMI: photospheric data (e.g. magnetograms)

SOHO: Solar Mission at L1 (Lagrange point 1), MDI – magnetograms, EIT: coronal images, LASCO: white light coronagraphs (C1,C2,C3)

Data Sources

STEREO (https://stereo.gsfc.nasa.gov): 2 solar spacecraft – different orbit than Earth – check 'Where is STEREO' https://stereo-ssc.nascom.nasa.gov/where.shtml

STEREO A and B – currently only STEREO A

EUVI: full disk coronal images (195A, 304A)

Cor 2: white light coronagraphs

Data Sources

BBSO: Big Bear Observatory
(www.bbso.njit.edu)
Ground-based solar observatory
Full disk images in H alpha

Data Sources

GONG: Global Oscillation Network Group

Part of National Solar Observatory (NSO):

network of 6 ground-based solar observatories

(around the world to continuously observe the sun)

https://gong.nso.edu

Full disk H alpha images, synoptic magnetograms

Data Sources

Glossary:

https://ccmc.gsfc.nasa.gov/RoR_WWW/presentations/Glossary_of_Space_Weather_terms.pdf